LAMELLAR INCLUSION IN OLIVINE FROM NAKHLA (SNC) METEORITE.

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Introduction: Nakhla is one of the SNC meteorites (Shergottites-Nakhlites-Chassignite) that are widely believed to have originated on planet Mars. Martian meteorites are of great importance in understanding the geology and chemistry of Mars. Nakhla is an igneous clinopyroxenite principally composed of cumulate augite and olivine grains set in a microcrystalline mesostasis. Olivine, in the proportion of 5~18 vol.% [1], has nearly homogeneous composition of Fa_{60}. Coexisting augite and olivine are not in equilibrium, reflecting diffusive re-equilibration of olivine with late stage liquid or subsolidus annealing [2]. Rounded magmatic inclusions (10-350 µm in diameter) are sometimes present in large subhedral olivines that are most likely to be representative of trapped parent magma [3]. It is noted that almost all olivines contain dark lamellar inclusions (*ca*., 1-2 µm in width and ~20 µm in dimension) that have specific crystallographic orientation against the host olivine. Here, we report analyses of these lamellar inclusions and discuss their possible petrogeneses.

Methods: We first analyzed lamellar inclusions in the thin section by electron microprobe. We also separated single olivine crystals (~0.5 mm in size) from a Nakhla rock chip, and made oriented sections after determining orientation of the crystals by X ray diffraction method (precession camera). The oriented sections were observed by an optical microscope, and then they were analyzed by high resolution SEM (Hitachi S-4500) with EDS at Mineralogical Institute, University of Tokyo.

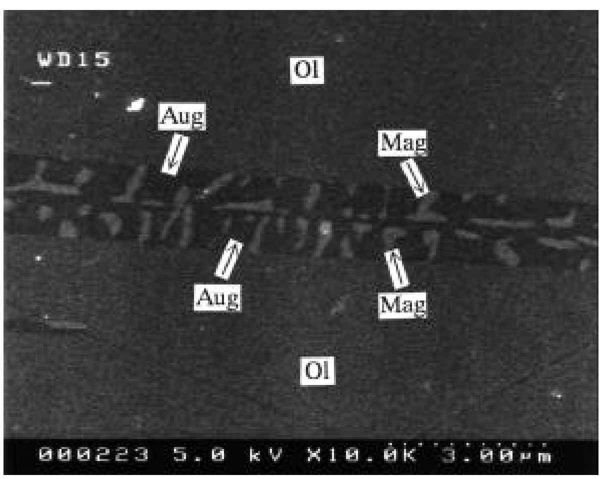

Fig. 1. Secondary electron photomicrograph of olivine in the Nakhla thin section by high resolution SEM. The width of the field is about 11.5 µm. Lamellar inclusion is about 2 µm in width. It is obvious that the inclusion is composed of two phases. EDS analyses indicate that the brighter area is magnetite and darker area is augite. Ol: host olivine, Mag: magnetite, and Aug: augite.

Results: Microprobe analysis of the inclusion shows that they contain ~17 wt% CaO. Al_2O_3 and Cr_2O_3 are both enriched and reach 1~2 wt%. The total sum is generally 2-3 wt% lower than the host olivine. The lamellar inclusion is a few µm in width. Therefore, the obtained composition must include those from the host olivine due to overlapping of the beam.

Observation of the oriented sections (perpendicular to *a* axis) by optical microscope displays that the inclusions develop perpendicular to *a* axis of the host olivine. Their inner structure is constituted by a black-colored dendritic texture on sub-micrometer scale. Secondary electron images (SEI) by high resolution SEM show that the lamellar inclusion has two phases inside (Fig. 1). EDS analysis of the brighter area indicates that Fe is the only element included. Because of the black-colored nature of the inclusion, the presence of Fe^{3+} has been suggested. Thus, this phase is considered to be magnetite. This is consistent with low total sum of the microprobe analysis for the inclusion and oxidizing environment on Mars. EDS analysis of the darker area indicates that it is augite. The composition of augite is $Mg_{35}Fe_{21}Ca_{44}$, and it is more Ca-rich than cumulus augite ($Mg_{38}Fe_{22}Ca_{40}$).

Discussions: It is suggested that the lamellar inclusion is composed of augite and magnetite. Such Ca-rich lamellar inclusion in olivine is rarely observed. The only report is kirschsteinite (CaFeSiO4) exsolution lamellae in olivine from an angrite meteorite [4]. Unlike them, the complex texture of the inclusion in Nakhla olivine indicates that they are not simple exsolved products. We have proposed three hypothetical models for the formation of the inclusion.

(1) *Oxidization of kirschsteinite lamella:* It has been known that wollastonite and magnetite can be formed by oxidization of kirschsteinite [5]. Consequently, augite and magnetite might be formed as an oxidized products from exsolution lamellae of Mg-bearing kirschsteinite. Because the host olivine has ~0.5 wt% CaO, initial kirschsteinite might have exsolved at low temperature (*ca*., 500- 600 ^oC).

(2) *Magmatic inclusion:* The lamellar inclusions have similarities to the rounded magmatic inclusions in their mineral assemblages, although they are dissimilar both in their sizes and textures. Formation history of the lamellar inclusion might have some references to the magmatic inclusion, as Treiman [3] reported various types of inclusion.

(3) *Low-temperature alteration product:* As the third possibility, the lamellar inclusions might be secondary phases formed by low-temperature post-magmatic alteration process. Because the inclusion shows dendritic precipitation of magnetite, it might be possible that they formed along the crack of the inclusion.

Although each hypothesis has some difficulties, we prefer the first hypothesis that the lamellar inclusion is an oxidized product of kirschsteinite lamella. In order to obtain accurate characterization of the lamellar inclusion, further study by TEM of ion-milled oriented sections is required.

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